



U.S. ARMY
RDECOM
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Directions in Engine-Efficiency and Emissions Research (DEER) Conference

3 October 2011



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Director**

Report Documentation Page			<i>Form Approved OMB No. 0704-0188</i>	
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1. REPORT DATE 03 OCT 2011	2. REPORT TYPE	3. DATES COVERED 00-00-2011 to 00-00-2011		
4. TITLE AND SUBTITLE Directions In Engine-Efficiency And Emissions Research (DEER) Conference			5a. CONTRACT NUMBER	
			5b. GRANT NUMBER	
			5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)			5d. PROJECT NUMBER	
			5e. TASK NUMBER	
			5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Army Tank Automotive Research Development ,and Engineering Center (TARDEC),6501 E. 11 Mile Road,Warren,MI,48397			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)	
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited				
13. SUPPLEMENTARY NOTES Directions in Engine-Efficiency and Emissions Research (DEER) Conference October 3-6, 2011				
14. ABSTRACT				
15. SUBJECT TERMS				
16. SECURITY CLASSIFICATION OF: a. REPORT b. ABSTRACT c. THIS PAGE unclassified unclassified unclassified			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 22
19a. NAME OF RESPONSIBLE PERSON				

What We Do

- Acquisition: Program Management
- Logistics: Industrial Operations, and Contracting
- Technology: Research, Development, and Life Cycle Engineering

The Magnitude

- Over 60% of the Army's Equipment and Systems (65% BCT's)
- Over 130 Allied Countries Own Our Equipment
- Approximately 3,300 Fielded Product Lines and 38,500 Components

The Product Lines

1. Mine Resistant Ambush Protected (MRAP)
2. Combat Vehicles
3. Armored Security Vehicle
4. Route Clearing Vehicle
5. Howitzers
6. Tactical Vehicles
7. Rifles / Machine Guns
8. Large Caliber Guns
9. Mortars
10. Rapid Fielding Initiative
11. Aircraft Armaments
12. Robotics
13. Soldier Uniforms & Equipment
14. Force Providers
15. Materiel Handling Equipment
16. Chemical Defense Equipment
17. Tactical Bridges
18. Fuel & Water Dist Equipment
19. Trailers
20. Watercraft
21. Rail
22. Construction Equipment
23. Commercial Vehicles
24. Fuel & Lubricant Containers
25. Sets, Kits & Outfits
26. Shop Equipment



We support a diverse set of product lines through their life cycles, from combat and tactical vehicles, armaments, watercraft, fuel and water distribution equipment, to soldier, biological, and chemical equipment.

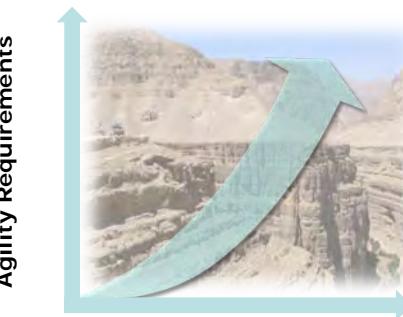
► Tactical Vehicles

Vehicle	Description	Units
Light Tactical Vehicles (LTV)	HMMWV vehicle variants made up of 1 ¼ ton payload class	163,661
Medium Tactical Vehicles (MTV)	14 variants in 2.5 and 5 ton payload class	43,143
Heavy Tactical Vehicles (HTV)	Heavy-duty trucks, 10 ton and up, used for cargo, moving heavy equipment, tractors, tankers, wreckers, fire fighting trucks, dump trucks and others	55,236
Mine Resistant Ambush Protected (MRAP)	A family of armored fighting vehicles designed to survive IED attacks and ambushes	10,902 (*16238 required)
Total		272,942

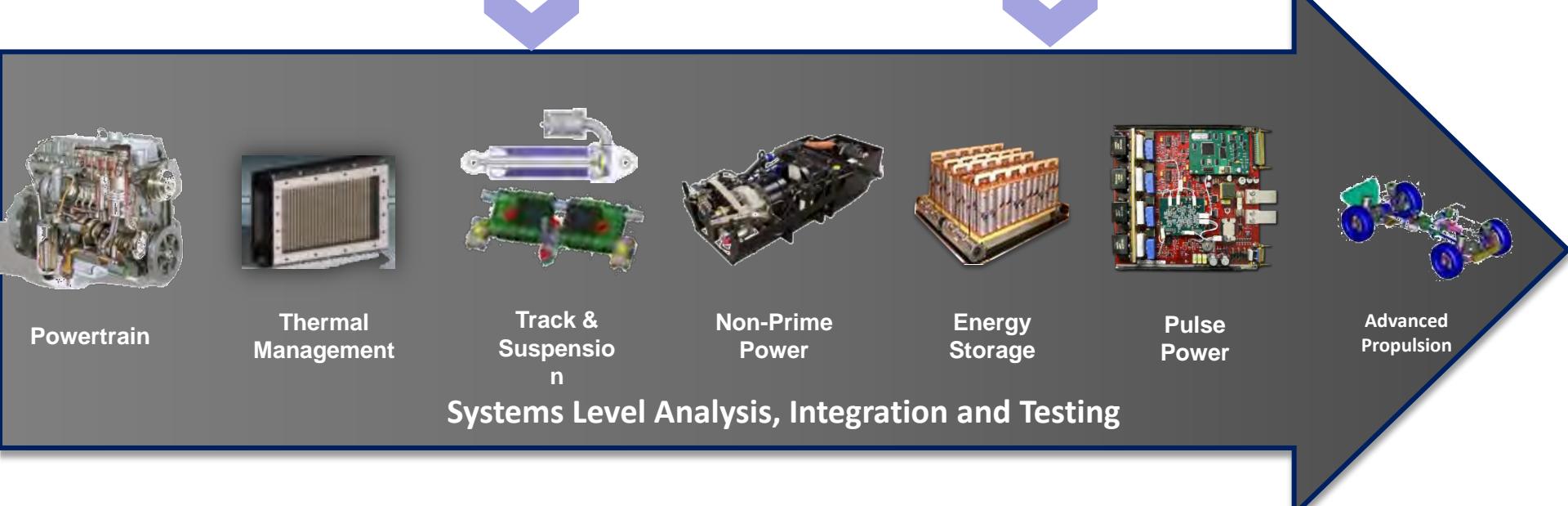
► Non-Tactical Vehicles

Vehicle	Description	Units
Passenger Vehicles	Sedans, station wagons, passenger vans, SUVs	86,138
Light Trucks	Vans, pickup trucks	42,665
Medium Trucks	Miscellaneous cargo, flatbed, boxvan, others	43,762
Trucks	Heavy-duty trucks	17,598
Other	Ambulances, buses and support vehicles	6,633
Total		196,796

- All tactical vehicles are considered medium or heavy-duty by commercial standards (they are above 10,000 GVW, and all use JP8)
- About 30 percent of non-tactical vehicles are also medium or heavy-duty
- In total, about 72% of the total DoD fleet is medium or heavy-duty vehicles



Increasing demands, operational flexibility, and inter-relationships
 Requires a Systems Engineering approach and investments in key technology areas



Power, Energy & Mobility



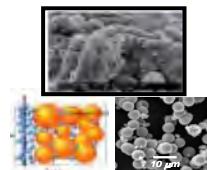
Newton-Euler Equations of Motion

$$\left. \begin{array}{l} \mathbf{M}\ddot{\mathbf{q}} + \mathbf{C}_q^T \boldsymbol{\lambda} = \mathbf{Q} \\ \mathbf{C}(\mathbf{q}, t) = \mathbf{0} \end{array} \right\}$$

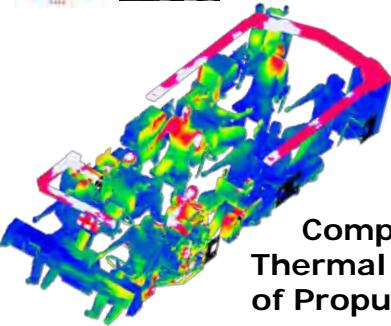
Solve for vehicle mobility and component loads

Vehicle Dynamics

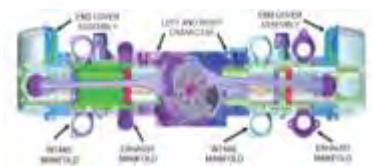
$$\left[\begin{array}{cc} \mathbf{M} & \mathbf{C}_q^T \\ \mathbf{C}_q & \mathbf{0} \end{array} \right] \left[\begin{array}{c} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{array} \right] = \left[\begin{array}{c} \mathbf{Q}_e + \mathbf{Q}_v \\ \mathbf{Q}_d \end{array} \right]$$



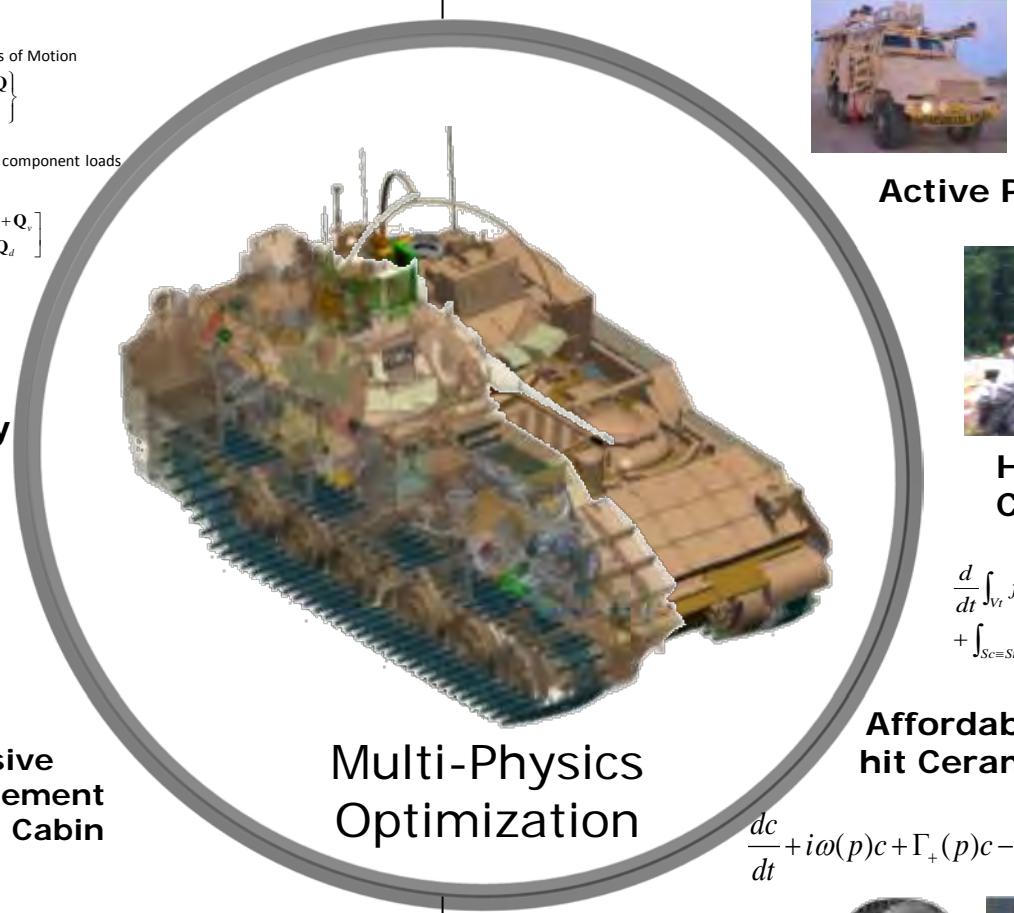
Hi-Energy, Hi-Density Energy Storage



Comprehensive Thermal Management of Propulsion & Cabin



High Power Density, Low Heat Rejection & Fuel Efficient Engines



Soldier & System Survivability



Active Protection Systems



Holistic Occupant Centric Protection

$$\frac{d}{dt} \int_{V_t} f(x, t) dV = \int_{V_c \equiv V_t} \frac{\partial f(x, t)}{\partial t} dV + \int_{S_c \equiv S_t} f(x, t) \bullet n dS$$

Affordable, Multi-hit Ceramic Armor



$$\frac{dc}{dt} + i\omega(p)c + \Gamma_+(p)c - \Gamma_-(p)c = f_n(t)$$



Fire and Toxic Fume Resistant Materials

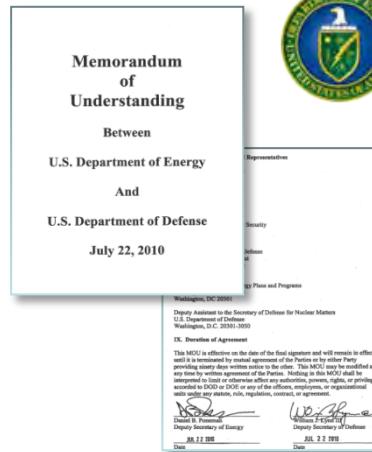
It's About Balancing Technology, Integration, Mission & Threat



AVPTA will move us toward reducing our reliance on fossil fuels.

Combines the intellect of the DA and the DOE to accelerate energy-related R&D initiatives.

Advanced Vehicle Power Technology Alliance (AVPTA) Breaking New Ground



22 July, 2010



18 July, 2011

- Partnership with true collaboration to enhance national energy security
- Demonstrate federal government leadership
- Provide shared capabilities and access to resources
- Accelerate technology development
- Drive innovation
- Increase the value of research investments
- Address national energy needs

Advanced Combustion Engines and Transmissions	Lightweight Structures and Materials	Energy Recovery and Thermal Management	Alternative Fuels and Lubricants	Hybrid Power Systems	Analytical Tools
Technical areas for potential joint activity:					
<ul style="list-style-type: none"> • High density, energy efficient powertrain • Extreme gains in engine efficiency ❖ Spray Visualization Project 	<ul style="list-style-type: none"> • Reduce weight to improve performance • Cost reduction for consumer market ❖ Carbon Fiber Project 	<ul style="list-style-type: none"> • Cost Improved efficiency, manage heat generation • Efficiency gains through waste heat recovery ❖ Thermoelectrics and Enabling Engine Project 	<ul style="list-style-type: none"> • Standardization & security • Efficiency gains through advanced oil formulations 	<ul style="list-style-type: none"> • Efficiency improvements ❖ CAEBAT Project ❖ Permanent Magnetic Project 	<ul style="list-style-type: none"> • Assessment/Design Trades



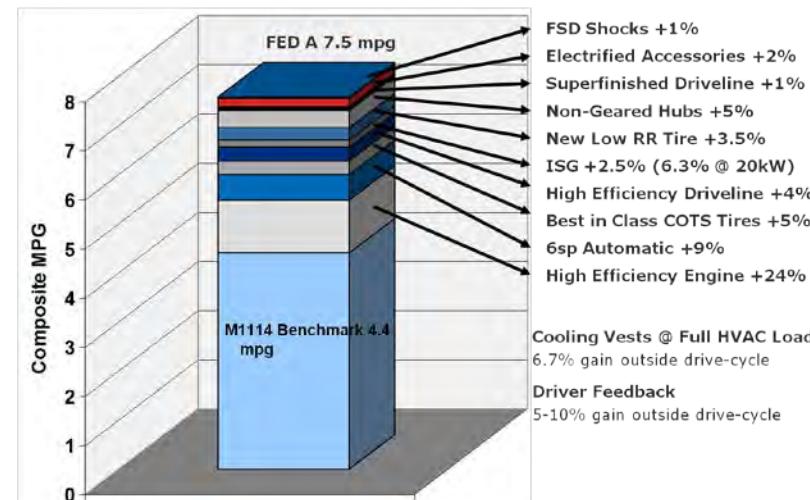
Driving results through collaboration



Designed to validate fuel-efficiency innovations, enhance Soldier safety and reduce Army's energy costs.

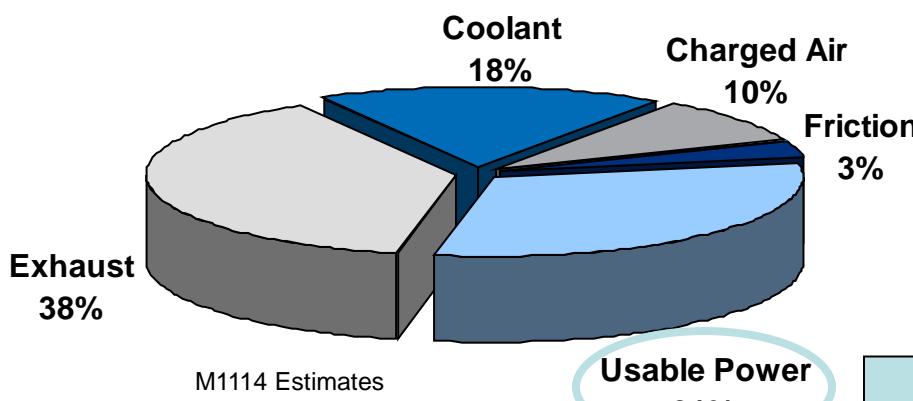
System engineering approach. Exceeded the original goal of 30% more fuel efficient than the M1114

Fuel Efficiency Demonstrator (FED)
OSD Sponsored, Army Implemented

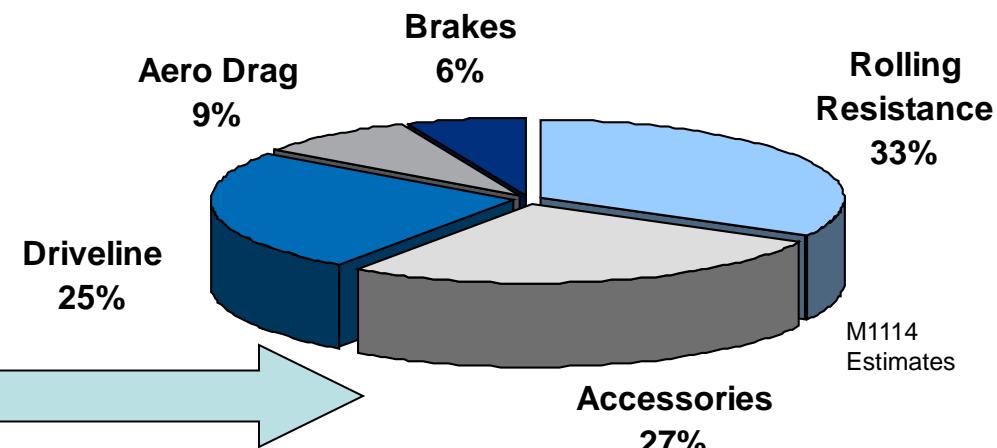


- Identify and assess technologies that support increasing fuel efficiency in a M1114 size vehicle and demonstrate them in a system level demonstrator
 - Alpha – Testing began July 2011
 - Bravo – Nov 2011 delivery
- Developed detailed models & simulations to evaluate energy generation, losses, recovery, etc.
- Engine Energy & Vehicle energy analysis and balancing

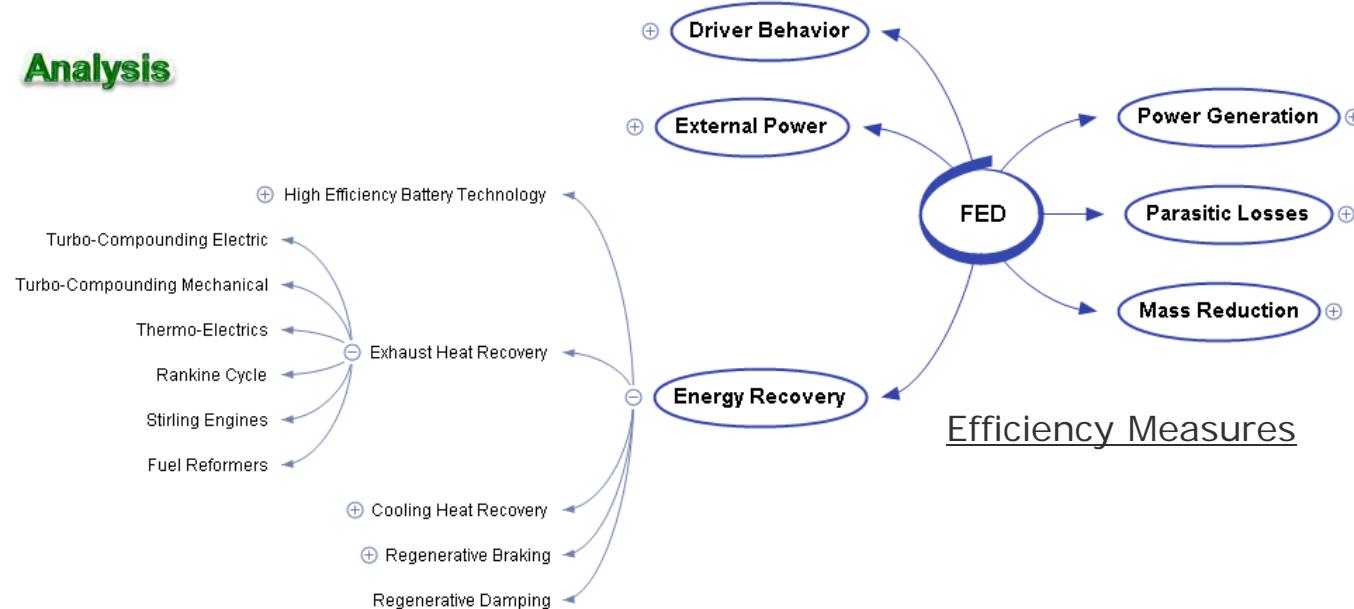
Engine Energy Balance



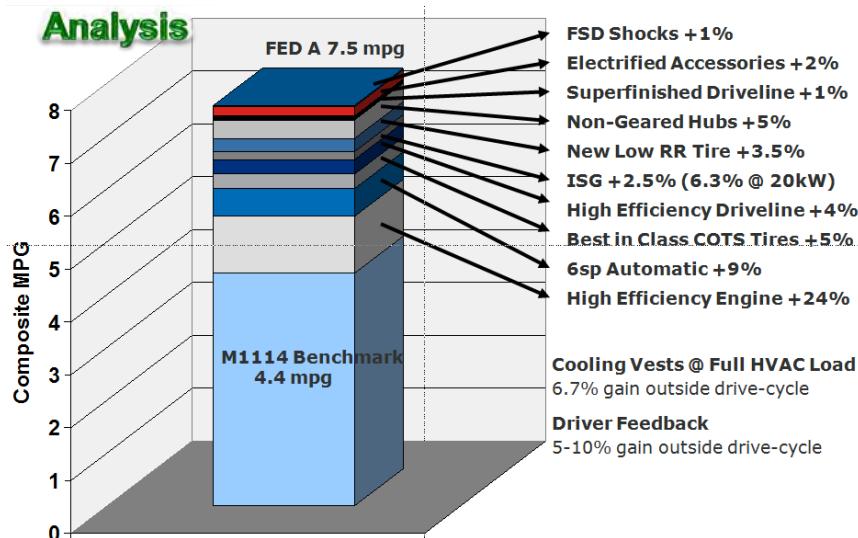
Vehicle Energy Balance



Analysis



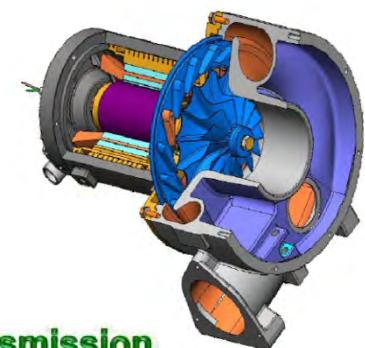
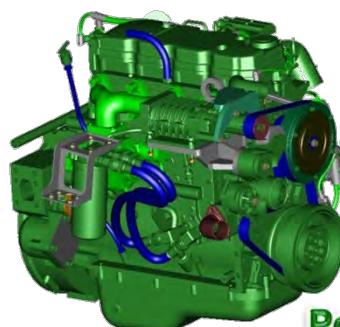
Analysis



200hp 4.5L I4 diesel; Calibrated for max efficiency.

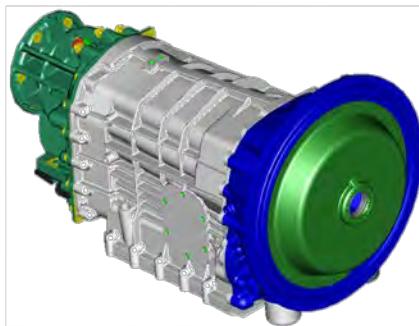
Right-sized for application

Electric Turbo-Compounding utilizes wasted heat energy.



Power Transmission

Greatest single contributor to upgrade efficiency is 7-speed dual clutch transmission, best non-hybrid efficiency option.



Power Transmission

35% rolling resistance improvement (pavement) using 22.5" commercial wheel w/ custom tread & tire compound.



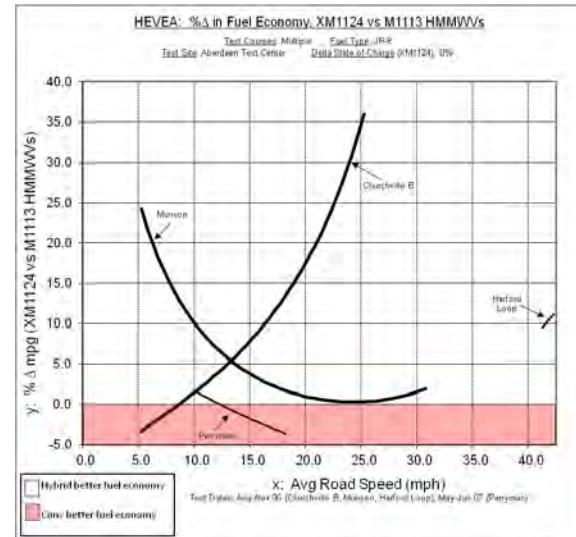
Materials



HEVEA - In 4 years, the Army developed physical & analytical methods for evaluating conventional and hybrid vehicles which have been accepted by the acquisition and industry communities, including SAE.

Hybrid Electric Vehicle Experimentation and Assessment (HEVEA)

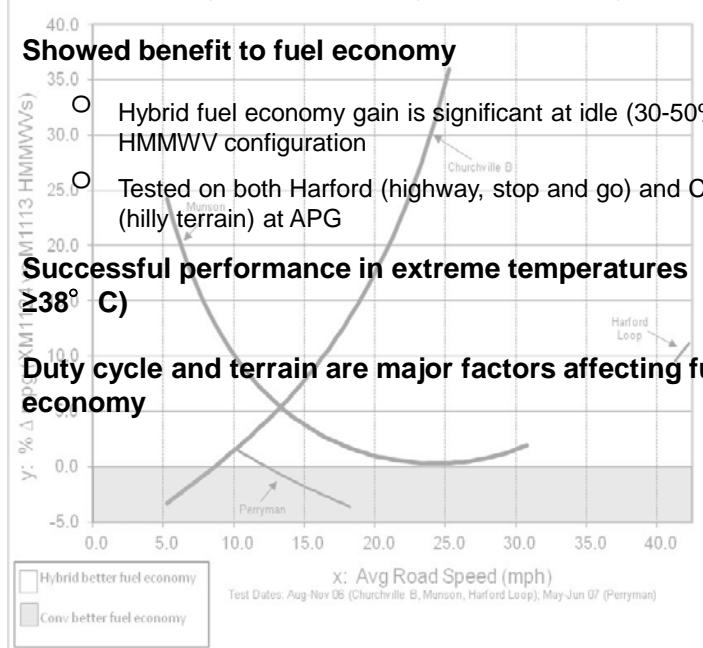
20 Vehicles (10 Conventional/10 Hybrid)



- Developed a standard testing procedure & methodology for testing HEV's
- Developed analytical tools for both assessment and evaluation
- Established credible/quantifiable data of HEV vice conventional vehicles (fuel economy, reliability,)
- Developed M&S methods

Accomplishments

- Developed analytical tools for both assessment and evaluation
 - Implemented as a design tool for the JLTV effort
 - Used on FED program
 - Sensitivity analysis of data ongoing
- Developed physical test for hybrid electric systems - the TOP
- Showed benefit to fuel economy
 - Hybrid fuel economy gain is significant at idle (30-50%) for test HMMWV configuration
 - Tested on both Harford (highway, stop and go) and Churchville (hilly terrain) at APG
- Successful performance in extreme temperatures (-32° to $\geq 38^{\circ}$ C)
- Duty cycle and terrain are major factors affecting fuel economy

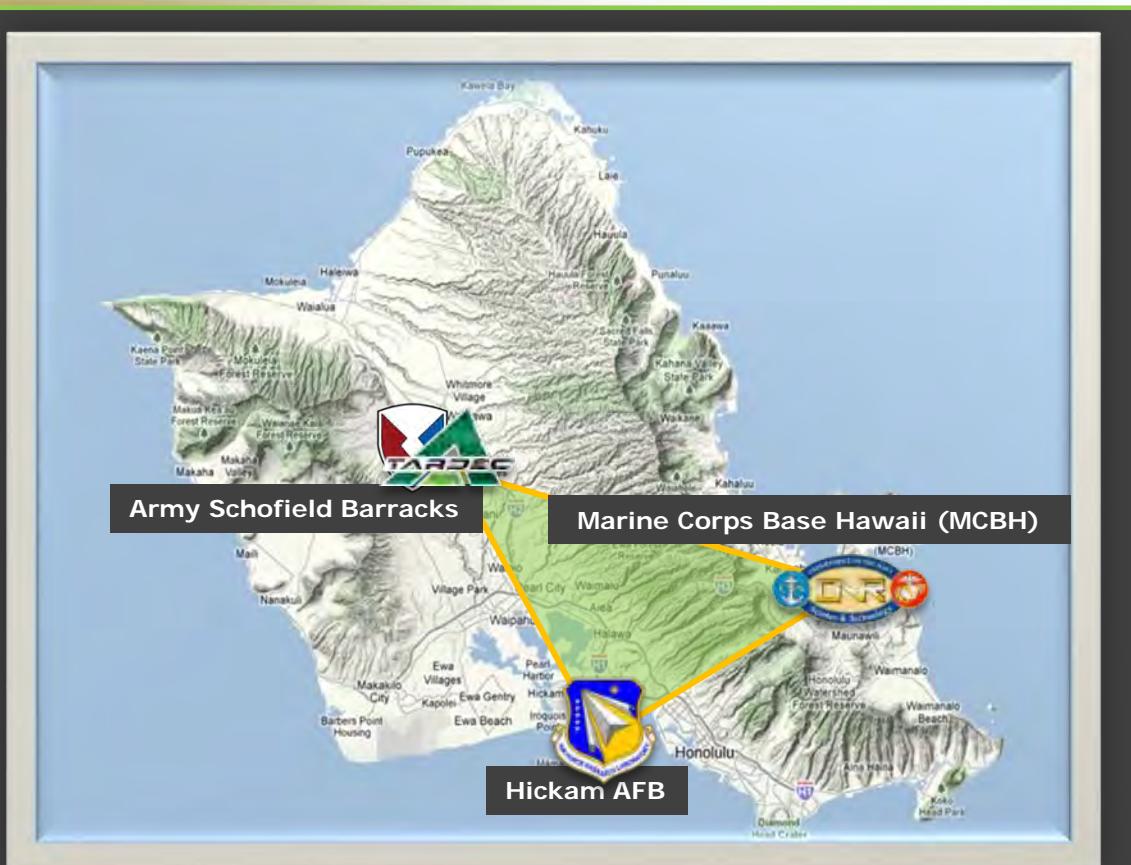


Hybrid-Electric Work to do

- Reliability** – Evaluate the reliability of technology in military environment
- Operational Analysis** – Assess technology value in operational scenarios
- Cost Analysis** – Conduct cost analysis of fuel savings versus cost incurred for a specific platform in an operational mode
- Life Cycle Cost Analysis** - Evaluate life cycle costs

Hybrid Electric Advantages

- Hybrid electric provides additional mission capabilities:
 - Power Generation – (On-board vehicle power)
 - Auxiliary Engine Support
 - Export Power
 - Silent operations



Hawaii's Energy from Oil

90%

HI Imports 51 million barrels of Oil Annually

\$7B

Hawaii's Supply of Oil (at any given time)

14-21 Days



Partnerships

- Hawaii Tri-Service Advanced Vehicle Working Group
- DOD-DOE Advanced Vehicle Power Technology Alliance
- PACOM/NORTHCOM SPIDERS JCTD
- State of Hawaii
- University of Hawaii-HNEI
- Hawaii Tri-Service Military Installations

TARDEC Involvement Achieves Goals

- Supports the increase in renewable energy
- Military as an early adopter
- Develop a competitive & sustaining industry
- **Army Hydrogen based Vehicles & Refueling**
- **Army Microgrid 1-**
 - 250kW sufficient to power a building
- **Army Microgrid 2-**
 - 450kW capable of powering 500-Soldier/Forward Operating Base

Hydrogen Vehicles with Internal Combustion Engines(H2ICE)



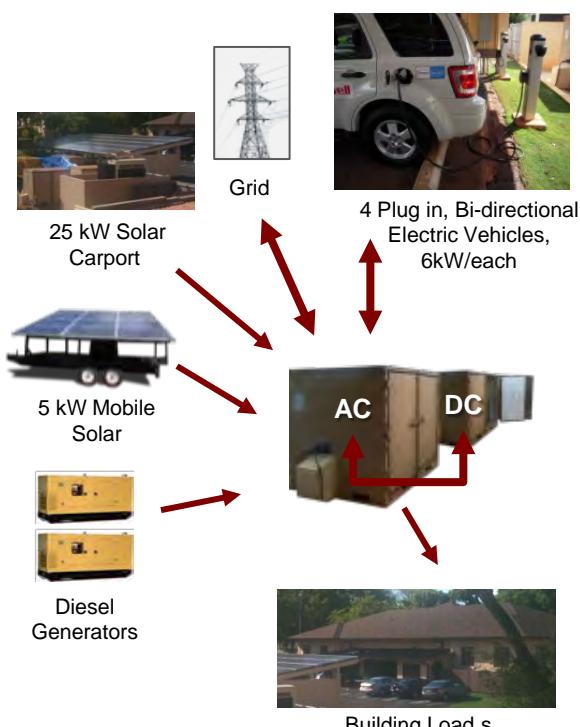
H2 Station JBPHH



15 H2ICE-vehicles

→ = Hydrogen
→ = Electric

U.S. Army Aloha Microgrid 1



Hydrogen Fuel Cell Vehicles

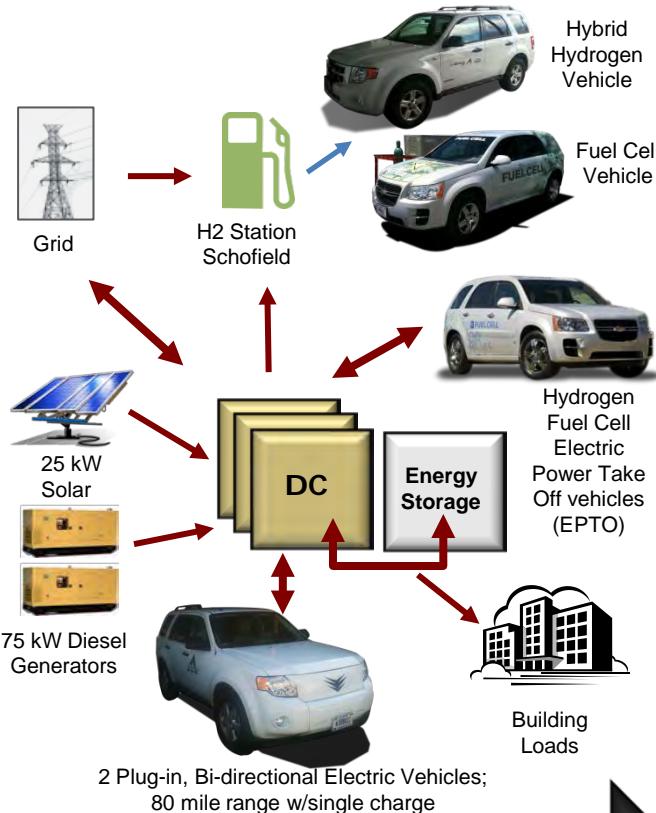


Tri-service H2 Network



10 Hydrogen Fuel Cell Vehicle- GM

U.S. Army Aloha Microgrid 2



2004	2008	2009	2010	2011	2012
Existing CONUS vehicles arrive in Hawaii Created the H2ICE network and tested	First Hawaii Advanced Vehicle Working Group Meeting Held Hybrid Hydrogen Vehicles; In operation in Hawaii since February 2009	Microgrid Planning Begins at Wheeler Army Airfield/Schofield Barracks	FCV deployed to Hawaii U.S. Army Aloha Microgrid 1; In operation in November	EPTO used by Marines in August 2011 General Motors Fuel Cell Vehicles; In Operation Starting August 2011	SPIDERS JCTD TARDEC Hydrogen Station; Planned operational for March 2012 U.S. Army Aloha Microgrid 2; Planned operational for January 2012

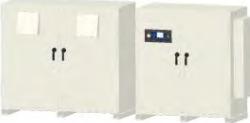
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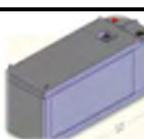
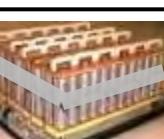
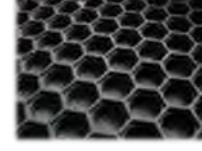


Lead. Innovate. Integrate. Deliver.

Back-up

Transfer Layer Technologies

Vehicle to Grid			Interface standards Physical, communication, cyber-security (SPIDERS – Ft. Carson)			Export power system development and demonstration
Microgrids			Enduring microgrid product development and demonstration (NetZero JCTD - Ft Irwin, others)			Integrated microgrid testbed demonstration (HI)
Hydrogen fuelled propulsion			Demonstration of fuel cells in non-tactical fleet (past Ft. Belvoir, current HI)			
Hydrogen Infrastructure			Hydrogen refuelling demonstration (past Selfridge, MI; future HI)			

Power Generation	 Diesel Engines	 Transmissions	 Traction Motors	 Integrated Starter Generator	 JP-8 Fuel Cells	 Turbine Engines	 Alternators	 Drivelines
Energy Storage	 Li-Ion / Ultracap Hybrid Energy Storage	 Capacitors	 Advanced Batteries	 Advanced Batteries	 Advanced Batteries	 Advanced Batteries	 Advanced Batteries	
Thermal Mgmt & Power Distribution	 Radiators	 Microgrids	 Power Controllers for Power Management	 Heat Recovery	 Power Converters /Inverters	 Advanced Electronics	 Cooling	 Thermal Architecture
Materials	 Lightweight Materials	 Thermal Interface Materials	 Wide Band Gap Materials (SiC)	 High Temperature SiC Modules	 Lightweight Structures	 High Temp Inductors	 High Temp Inductors	
Fuels & Lubricants	 Qualifications & Specifications	 Biomass Energy (Renewable)	 Conversion Process	 Single Fuel				

Electronic Power Conditioning & Control Distributed Generation

Vehicle Inputs



Plug-in Hybrid Electric Vehicles (PHEV)



Renewable Inputs



Mobile Encampment Waste to Electrical Power (MEWEPS)

Generator Inputs

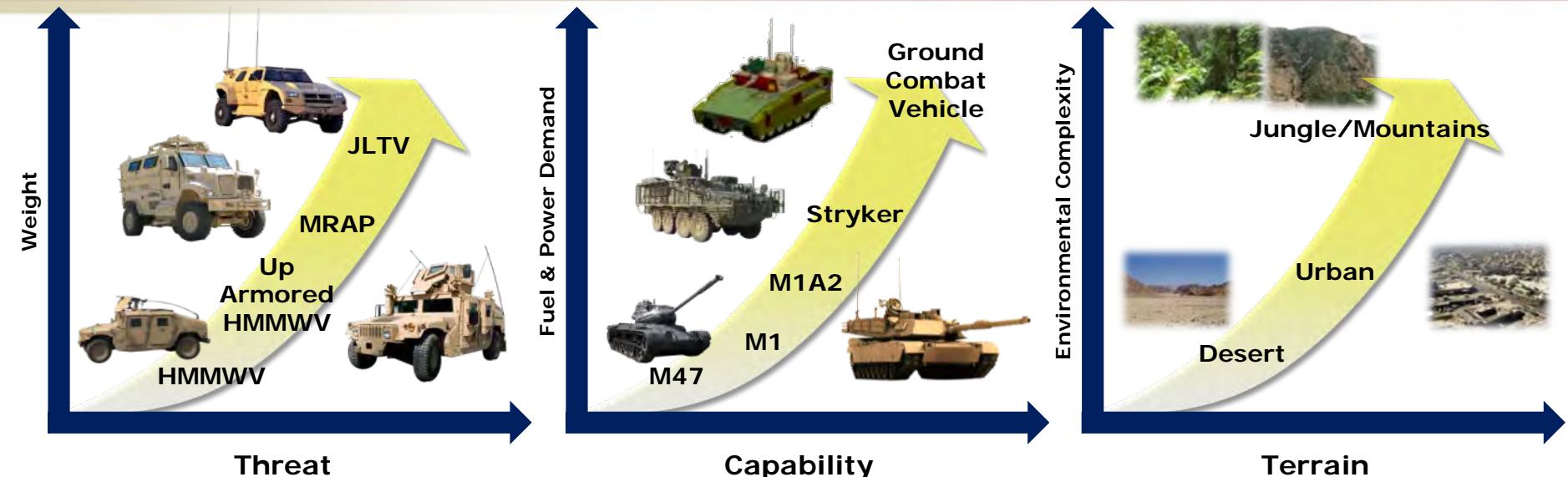


Solar

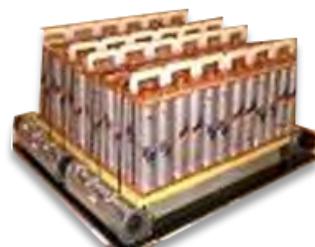
Tactical Quiet Generator (TQG)



Supply – Infrastructure - Demand



Increasing Demands and Operational Flexibility
Require Strategic Investments in Key Areas



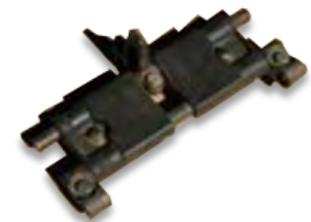
Energy Storage



Power Generation & Control



Thermal Management



Track & Suspension

